Single Event Effect Test Report
on IEEE 1394 Testing at
Brookhaven National Laboratories and TRIUMF

6/25/01 & 7/12/01

Hak S. Kim
Jackson & Tull Chartered Engineers

Christina Seidleck
Raytheon Corporation

Paul Marshall
Consultant

Kenneth A. LaBel
NASA-GSFC

I. Introduction

Radiation tests were performed on IEEE1394 Open Host Controller Interface (OHCI) Chipsets from two manufacturers to evaluate Single Event Effects. The tests were performed at two different facilities, Brookhaven National Laboratory (BNL) and TRI-University Meson Facility (TRIUMF). The primary focus during the BNL test was heavy ion-induced Single Event Latchup (SEL) while the focus during the TRIUMF test was full Single Event Upset (SEU) and Single Event Functional Interrupt (SEFI) to protons.

II. Devices Tested

IEEE1394 OHCI Chipset consists of two devices, Link Layer Controller (LLC) and Physical Layer (PHY). Chipsets from Texas Instrument (TI) and National Semiconductor Corporation (NSC) were tested. These chipsets were mounted on the development board from the respective manufacture. Table 1 shows the part numbers, Lot and Date Code (LDC), and the development board tested.

Manufacture	LLC		PHY		Development Board
	Part No	LDC	Part No	LDC	
TI	TSB12LV26PZT	CA-OAAO45T	TSB41AB3PFP	OCC4RTT	TSBKOHCI403
NSC	CS4210VJG	VS052ABC4	CS4103VHG	VS052ABC4	CS4210A-DK

Table 1: Summary of Devices Tested

III. Test Setup

A. Hardware

Two personal computers (PCs) with PCI slots were used in the test. Each had an IEEE1394 board. One of the PCs with the devices-under-test (DUTs) was placed in the beam line while the other was placed in a remote area. The two PCs were connected by their 1394 interface via a 10 ft 1394 cable for data communication. A PCI bus isolation card was placed between the DUT board and its host PC. This card enables current consumption readings from the +5V supply to the DUT board from the host PC via the PCI interface. A HP34401A Digital Multi-Meter (DMM) was used to read and record this supply current. Refer to Figure 1 for the hardware setup. Figure 1-A and Figure1-B show the photographed images of a test board.

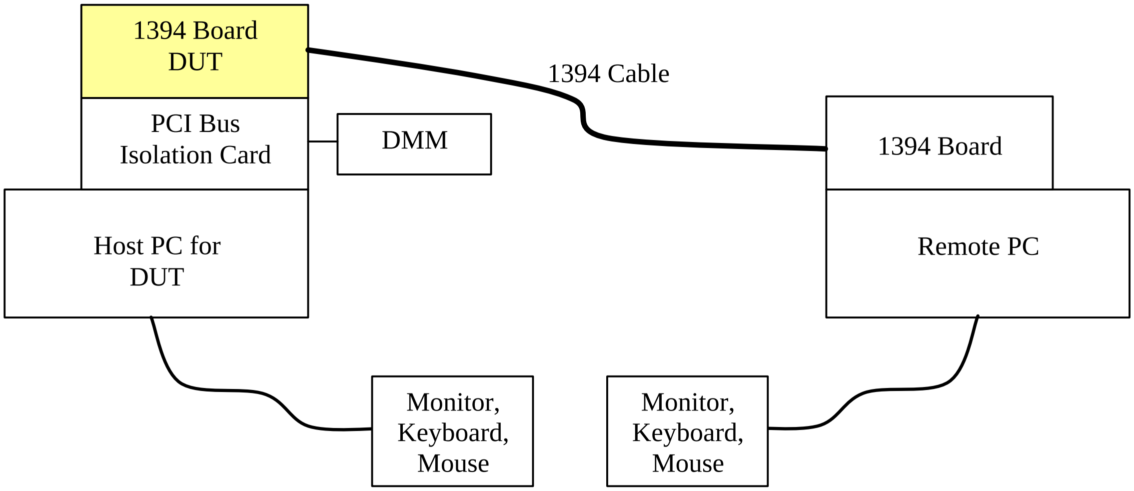

Figure 1: Test Setup for IEEE1394 Radiation Test

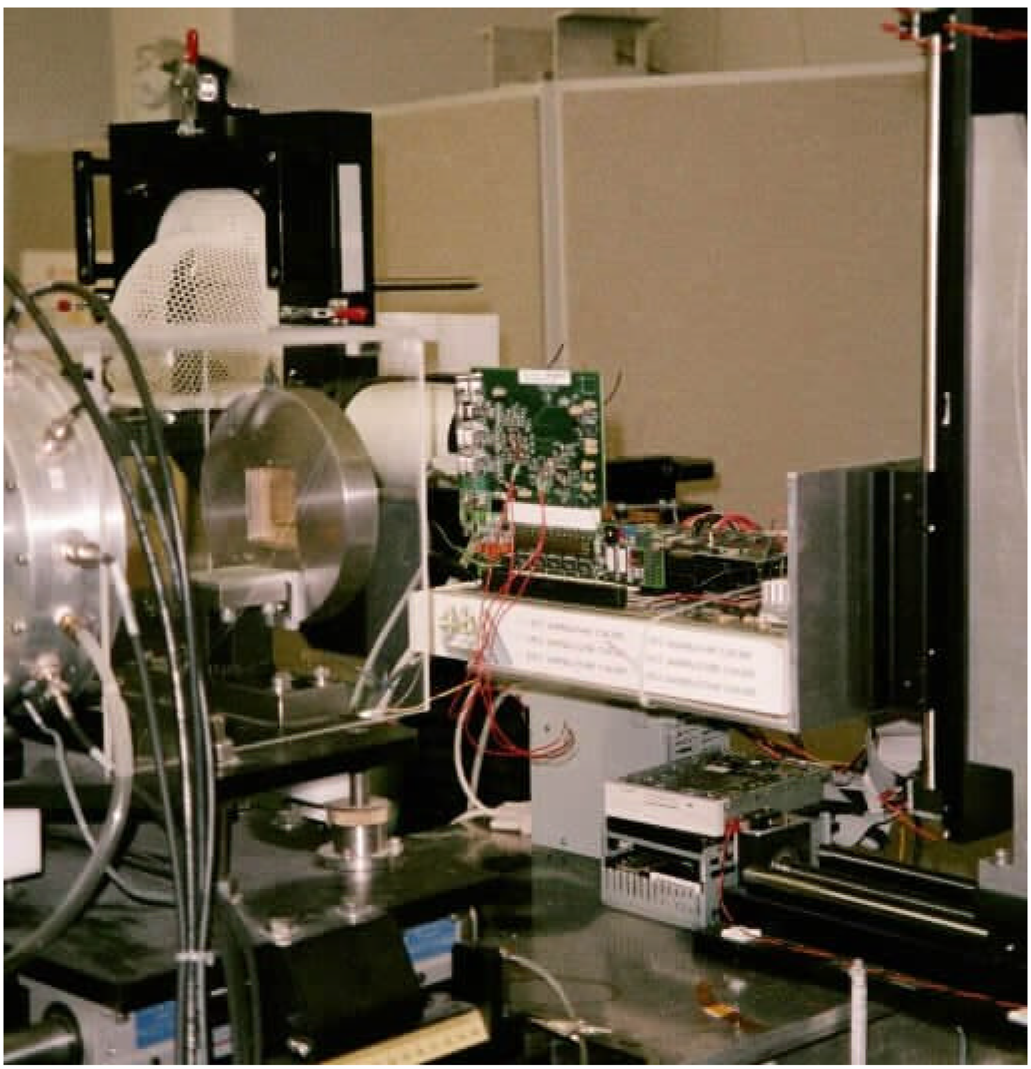

Figure 1-A: Front View of IEEE1394 Test Board in Beam Line (TRIUMF)

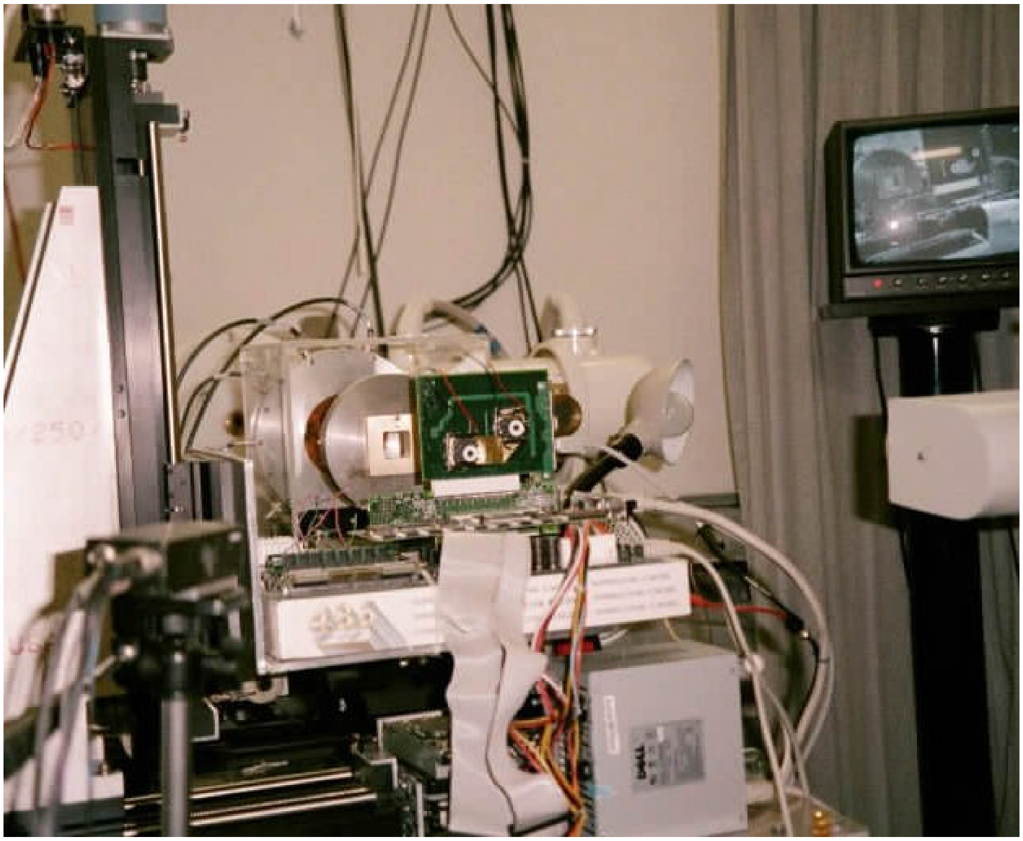

Figure 1-B: Rear View of IEEE1394 Test Board in Beam Line (TRIUMF)

B. Software

Custom software was developed using C++ under a Windows/NT environment. It is essentially a ping-pong program that enables communication between two PCs via IEEE1394 connection. The speed of the communication was 100 Mbps and the mode was asynchronous.

Since the main objective of the BNL test was to study SEL, the software for this was limited to setting up a proper data communication that would ensure the functioning of 1394 traffic and functioning of DUT board/PC. For the TRIUMF test, however, register values of the DUT board were scrubbed and sent via an asynchronous block packet to the remote PC for error examination.

IV. Test Procedure

A. BNL

A total of 32 tests, each with Ni ions at an LET of 27 MeV cm^2/mg(Si), were conducted. The supply was monitored to provide indication of latch-up. Using a remote 1394 terminal, functionality of the DUT terminal prior to, during, and after DUT irradiation was verified. Testing was halted whenever there was a sharp rise in the supply current, whenever a degree of functionality was lost with the DUT computer to assure that the 1394 DUT interface was properly powered, or when a test fluence of $1x10^7$ ions/cm^2 was reached.

Three samples of each of the TI DUTs and two samples of each of the NSC DUTs were evaluated for failures.

B. TRIUMF

A total of 77 tests were conducted to characterize the SEE of both the PHY and LLC. Two copies of the TI hardware and one copy of the NSC hardware were evaluated with 105 MeV protons.

IV. Test Result

A. BNL

In most cases, tests were interrupted because the DUT 1394 interface or DUT computer were not operable and we were not able to determine that the parts were properly powered for further latch-up testing. These errors were most likely SEFIs since they appeared to be non-destructive, and resetting the system would restore function. It should be noted that a similar result would be expected for a mini-latch-up failure, which would also be indicated by a sudden increase in the supply current.

The following types of SEFI were observed. All errors were accompanied by data communication lockup.

- 1394 Cable lockup – A quick removal and reconnection of 1394 cable restored the communication.
- DUT Computer OS error – Desktop icons of Operating System were reconfigured.
- DUT Computer lockup – DUT computer did not respond to any input device.
- DUT Computer Register Dump – DUT computer dumped the NT register values and locked up.
- DUT Computer Self Reboot – DUT computer rebooted itself.

To restore the 1394 functionality, following steps were taken progressively.

- Software Reset – A Bus reset command was issued by the remote computer.
- Cable Reset – 1394 cable was removed and reconnected physically.
- DUT Computer Reset – DUT computer was rebooted using warm-boot.
- DUT Computer and Remote Computer Reset – Both DUT computer and remote computer were rebooted by recycling power.

The more serious concern was for large current spikes and destructive failures that would not clear with power cycling. For this reason, tests were performed where the DUT was continuously exposed with Ni ions even though the 1394 communication link was lost. On the TI DUTs, current increases from ~ 35 mA to about 400 mA were noted, but all three DUT sets were still functional after Ni ion fluences greater than $1x10^7$ ions/cm^2 and power cycling. Similar current increases in current were noted for the NSC boards, but they no longer appear to be functional after exposure to fluences of $1x10^7$ ions/cm^2. The post-radiation analysis confirmed the functionality of TI boards and non-functionality of NSC boards. NSC boards did not produce proper self-ID for to allow entry onto the IEEE1394 network system.

Table 2 summarizes the BNL heavy ion test result.

Device Number	Device Type	Average SEFI Cross-Section (cm^2)	Standard Deviation (cm^2)	Note
TSB12LV26PZT	LLC	2.52E-5	4.70E-5	
CS4210VJG	LLC	2.36E-7	-	Single run. Other runs resulted unrecoverable failures.
TSB41AB3PFP	PHY	5.81E-4	1.02E-2	
CS4103VHG	PHY	3.95E-5	-	Single run. Other runs resulted unrecoverable failures.

Table 2: Summary of IEEE1394 Heavy Ion Test Results

Figure 2 plots the cross-section of LLC SEFIs.

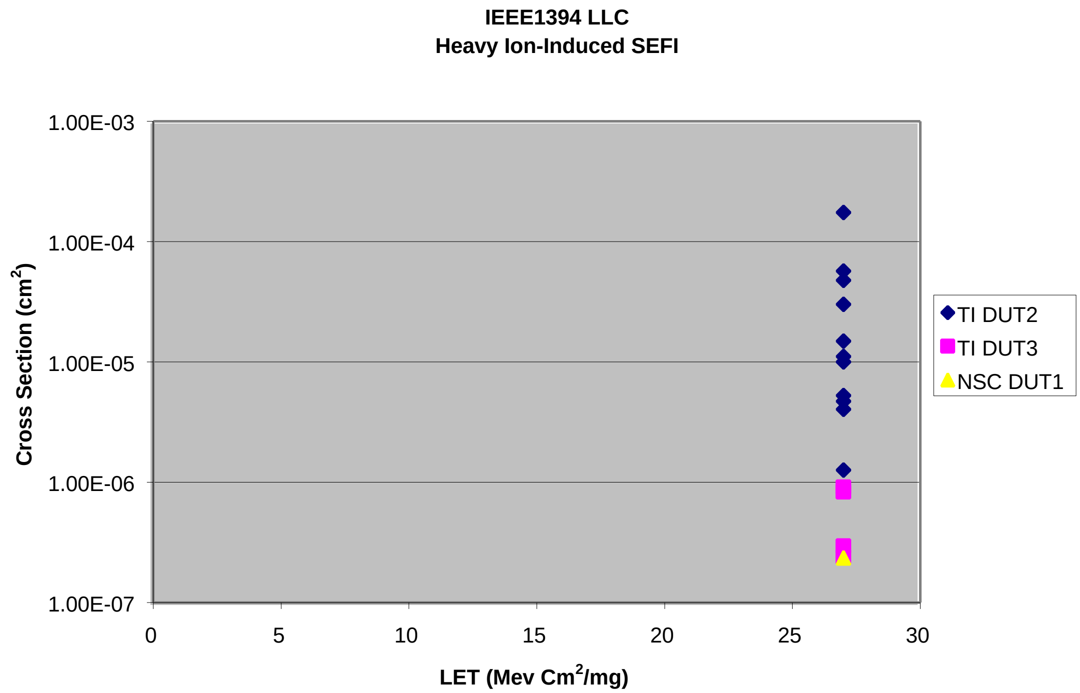

Figure 2: IEEE1394 LLC Heavy Ion-Induced SEFI Cross-Section

Figure 3 plots the cross-section of PHY SEFIs.

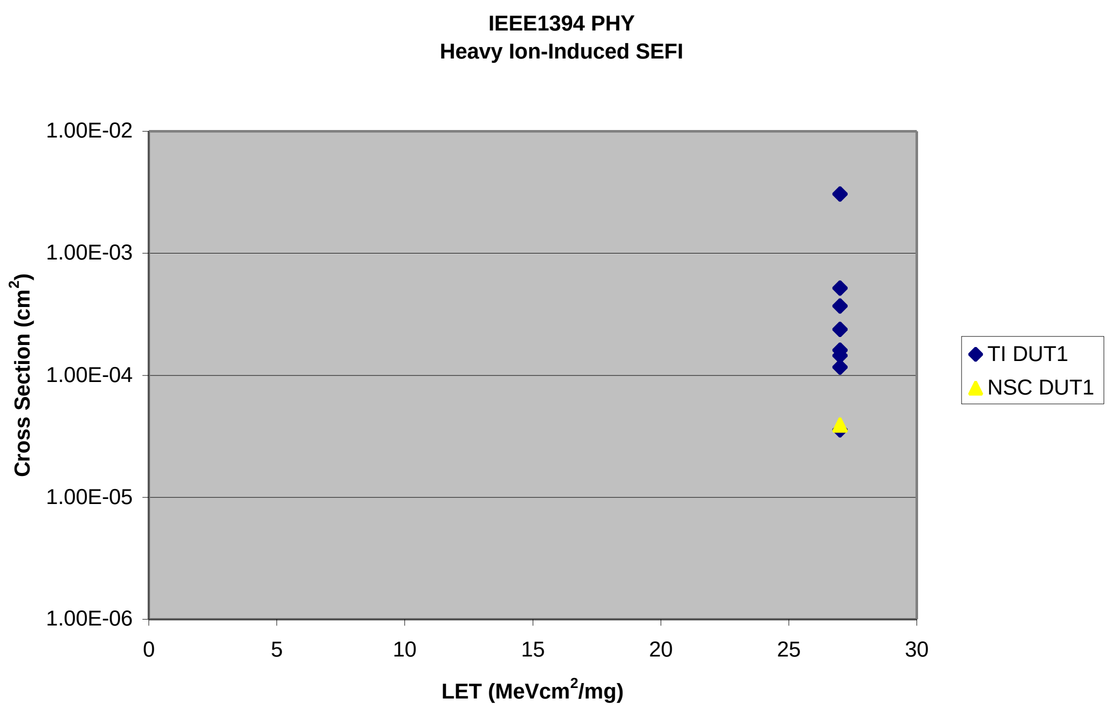

Figure 3: IEEE1394 PHY Heavy Ion-Induced SEFI Cross-Section

B. TRIUMF

Register values of LLC and PHY chips were gathered from the DUT and compared to pre-charted values. All mismatches were noted and recorded.

Register testing was broken down into two tests, OHCI/PCI (LLC) and PHY. For the LLC test 42 out of a possible 102 OHCI registers and 21 out of a possible 22 PCI registers were monitored for errors. Errors observed in these registers were single bit in nature. Table 3 shows summary of LLC register errors caused by protons.

Device Number	Device Type	Average SEFI Cross-Section (cm^2)	Standard Deviation (cm^2)	Note
TSB12LV26PZT	LLC	1.88E-10	1.73E-10	
CS4210VJG	LLC	3.04E-10	-	Single run with register errors

Table 3: IEEE1394 LLC Register Errors induced 105 MeV Protons

Figure 4 shows the SEU cross-section of LLC register errors.

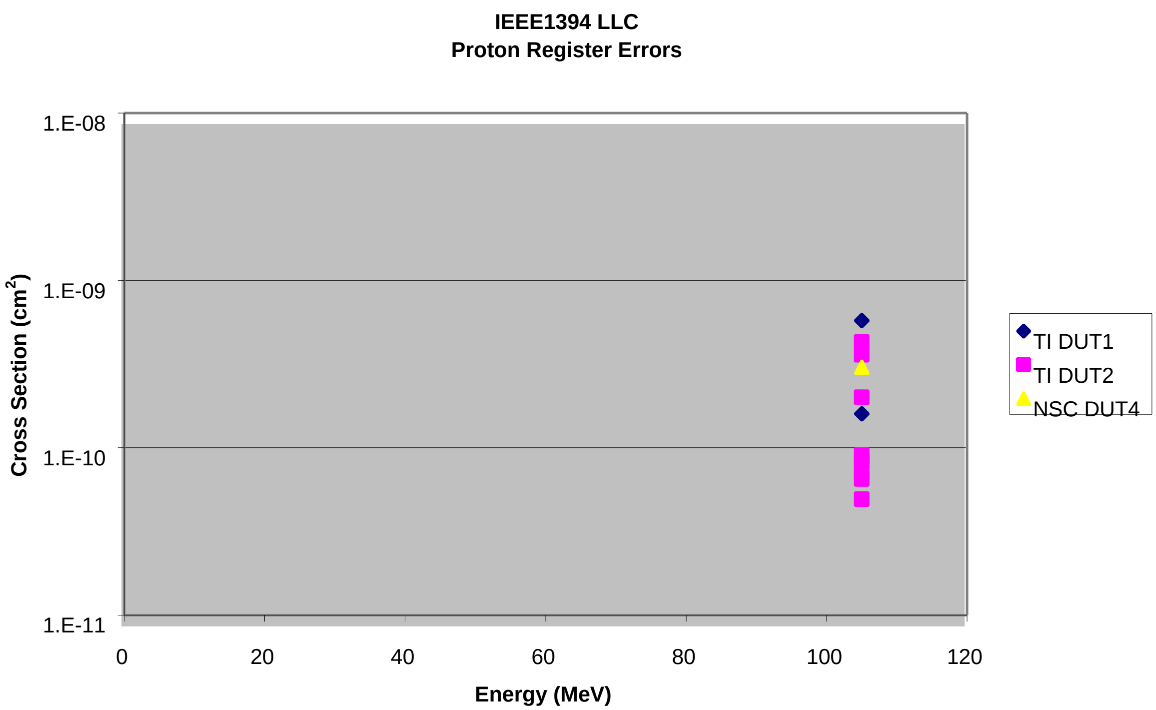

Figure 4: IEEE1394 LLC Register Error Cross-Section

Due to the volatility of the PHY registers, this test was accomplished by either a visual monitoring and recording of the 10 register values or by the passing of a known data pattern from the DUT to the controlling computer. In the first case, errors observed were single bit in nature. In the second case, the data never deviated from the expected value.

As it happened during BNL test, there were many test interrupts due to either SEFI or mini-latch-up type conditions that required halting of the beam exposure. All the SEFI types that appeared during the BNL test were also observed during the TRIUMF test as well. All link lockups were recovered by software reset, by DUT Computer warm-boot, or by power recycling of both DUT and remote PCs except one case (TI PHY) in which a FAT corruption error required a file to be renamed before the link could be restored. In some cases, board current did spike to above 1 Amp on the NSC board during exposure of the PHY chip, but a power recycle recovered the link. Cable Reset was not performed because DUT and remote PCs were located target area, about 100ft away from the control area, in a locked room. Refer to previous section for the description of different types of SEFI and the recovery procedure. Table 4 summarizes proton-induced SEFI results.

Device Number	Device Type	Average SEFI Cross-Section (cm^2)	Standard Deviation (cm^2)	Note
TSB12LV26PZT	LLC	1.48E-10	1.45E-10	
CS4210VJG	LLC	2.56E-10	1.63E-10	
TSB41AB3PFP	PHY	5.98E-11	5.96E-11	One incident of FAT corruption
CS4103VHG	PHY	1.46E-10	1.09E-10	>1 Amp current consumption

Table 4: Summary of IEEE1394 SEFI induced by 105 MeV Protons

Figure 5 and Figure 6 depict LLC SEFI cross-section and PHY SEFI cross-section respectively.

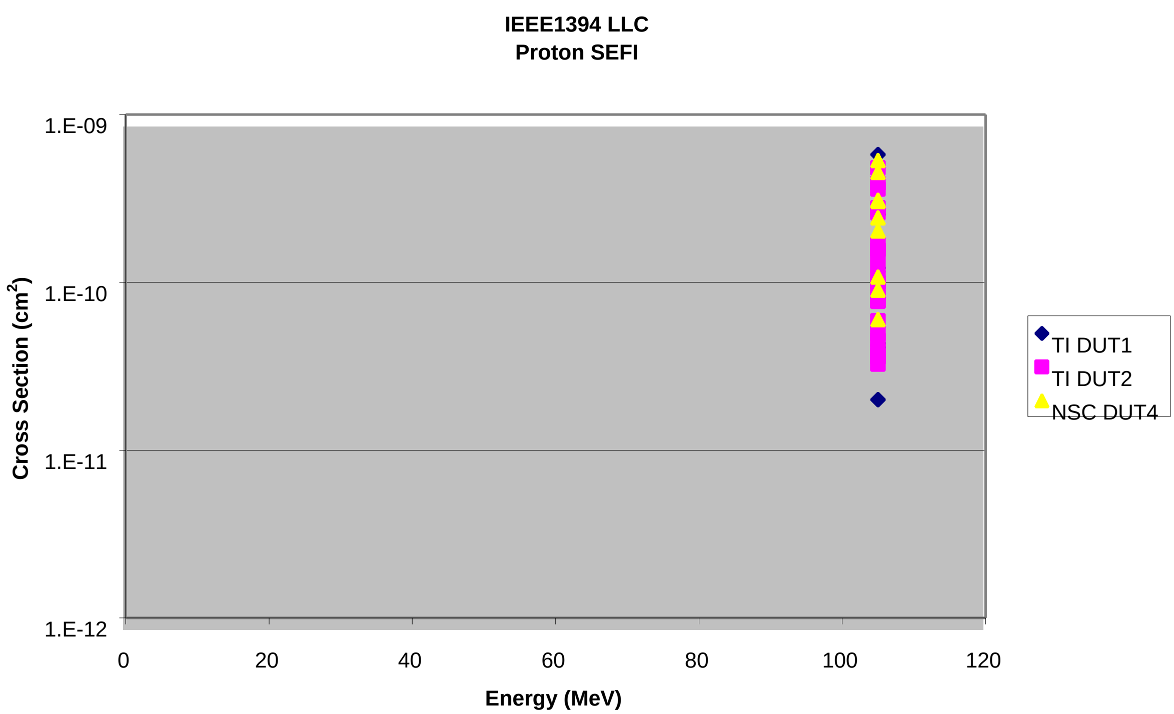

Figure 5: IEEE1394 LLC Proton-Induced SEFI Cross-Section

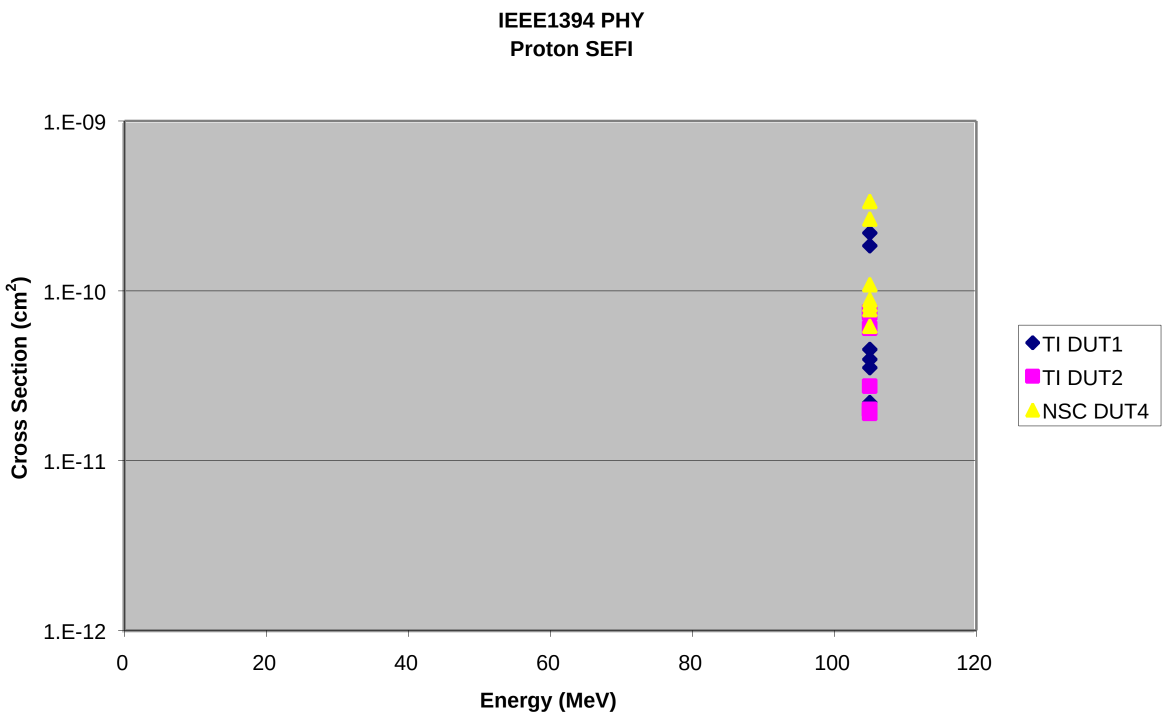

Figure 6: IEEE1394 PHY Proton-Induced SEFI Cross-Section

Dose levels of >50k rad(Si) for TI DUTs and >35K rad(Si) for NSC DUTs did not seem to adversely affect the functionality.

Test logs from both BNL and TRIUMF tests are available upon request.

V. Acknowledgements

We would like thank James Forney at Jackson & Tull, Kent Larson and Mike Worcester at Boeing Corporation, Timothy Irwin at QSS, and Tony Sciarini at Orbital Science Corporation for their supports in the test efforts.